Multi-resolution synergy of optical, thermal and SAR data for mapping of wetlands and permafrost on Tibetan Plateau

Kropáček, Jan ; Ye, Qinghua ; Leiterer, Reik ; Hochschild, Volker

Abstract: Potential of various techniques that utilize data from multiple sensors for mapping of wetlands on Tibetan Plateau have been evaluated. Optical and thermal infrared bands from Landsat and Corona together with SAR data from TerraSAR-X, ALOS/PALSAR have been used. Closed basin of Nam Co ('Co' means lake) (30° N, 90° E) has been selected as the study area. It belongs to the zone of discontinuous permafrost. Time series of Landsat data has been complemented by Corona image from 1965 and used to analyze changes of wetland area. Interpretation of wetlands from Corona image from 1965 features high quality. It was used as reference for comparison with time series of Landsat optical data with support of its thermal infrared band. Pauli decomposition image from ALOS PALSAR clearly has good potential usage in wetland mapping. The wetland area was relatively stable in the study region. Some parts of wetlands have been flooded by the lake transgression since 1965. In order to understand overall trend, more research has to be carried out in terms of scale, both in time and space. Relationship between surface properties of wetlands and underlying permafrost layer has to be better understood by further research.

Originally published at:
Kropáček, Jan; Ye, Qinghua; Leiterer, Reik; Hochschild, Volker (2009). Multi-resolution synergy of optical, thermal and SAR data for mapping of wetlands and permafrost on Tibetan Plateau. In: ESA Conference Earth Observation and Water Cycle Science, Frascati (I), 18 November 2009 - 20 November 2009. European Space Agency * Communication Production Office, online.

Multi-resolution synergy of optical, thermal and SAR data for mapping of wetlands and permafrost on Tibetan Plateau

Jan Kropáček[(1)], Qinghua Ye[(2)], Reik Leiterer[(3)], Volker Hochschild[(4)]

[(1)] Department of Geography, University of Tuebingen, Tuebingen, Germany, Email: jan.kropacek@uni-tuebingen.de
[(2)] Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Beijing, China, Email: yeqh@itpcas.ac.cn
[(3)] University of Jena, Jena, Germany, Email: reik.leiterer@uni-jena.de
[(4)] Department of Geography, University of Tuebingen, Tuebingen, Germany, Email: volker.hochschild@uni-tuebingen.de

ABSTRACT

Potential of various techniques that utilize data from multiple sensors for mapping of wetlands on Tibetan Plateau have been evaluated. Optical and thermal infrared bands from Landsat and Corona together with SAR data from TerraSAR-X, ALOS/PALSAR have been used. Closed basin of Nam Co ('Co' means lake) (30° N, 90° E) has been selected as the study area. It belongs to the zone of discontinuous permafrost. Time series of Landsat data has been complemented by Corona image from 1965 and used to analyze changes of wetland area. Interpretation of wetlands from Corona image from 1965 features high quality. It was used as reference for comparison with time series of Landsat optical data with support of its thermal infrared band. Pauli decomposition image from ALOS PALSAR clearly has good potential usage in wetland mapping. The wetland area was relatively stable in the study region. Some parts of wetlands have been flooded by the lake transgression since 1965. In order to understand overall trend, more research has to be carried out in terms of scale, both in time and space. Relationship between surface properties of wetlands and underlying permafrost layer has to be better understood by further research.

Key words: remote sensing, mapping of wetlands, permafrost, Tibetan Plateau, Nam Co, thermal infrared band, TerraSAR-X, ALOS/PALSAR, Landsat, Corona

1. INTRODUCTION

Wetlands can be characterized in general as a dynamic ecosystem vulnerable to climate change. High elevation wetlands on Tibetan Plateau play an important role in water and energy exchange processes in the area that is important for evolution of Asian Monsoon and which is the same time the source of major Asian rivers.

The Basin of Nam Co Lake has been selected as study area since it represents well the close hydrologic systems of central Tibet and since there is a field station of Chinese Academy of Science that carries out various meteorological observations [1] and serves as a base for field survey. The Nam Co basin is cold and arid with Arctic-Alpine Climate. Annual precipitation is about 300-400mm and occurs mainly in the summer period [5]. The basin is in zone of discontinuous permafrost.

The major objective of this work is to examine the capacity of different remote sensing data for mapping of area and characteristics of wetlands in Central Tibet on example of Nam Co basin. Our work is aimed also at understanding of relation between the surface properties of wetlands and the underlying permafrost layer.

Wetlands play an important role in water balance of the basin by their influence on runoff and evapo-transpiration. Loss of wetlands in this region would have serious consequences for local community. Wetlands are of crucial importance for livestock since they host long stem grasses that can feed animals during sudden summer snow fall events that make other grass in the area inaccessible. It also provides material for mud bricks and ensures availability of water for surrounding settlements during dry periods.

The Wetlands of Nam Co area are formed by a layer of organic soil few tenths of centimeters deep. There is no *sphagnum* moss present. The surface is covered by of structure of hummocks and hollows. Hollows are filled with water under wet conditions and hummocks support long *cobresia* grasses. Hummocks are usually around 30 cm high. Wetlands are distributed mainly in vicinity of the lake shore or rivers and then also on slopes at foothills of surrounding mountains. On the foothills they can be found on slopes up to 8 degrees of inclination.

The Nam Co basin belongs to zone of discontinuous permafrost. In the steeper parts wetlands are supported by underlying impermeable frozen layer in summer period. It has been observed that some parts of these wetlands become dry and vulnerable to degradation whereas other parts stay water logged during all summer. In the dry parts no frozen layer was detected by sounding to 100 cm of depth in August. This suggests that presence of surface water in wetlands in the summer can indicate changes in extent of close-to-surface permafrost.

Figure 1. Ongoing degradation of wetland in its dryer part, where no surface water as well as no frozen layer were detected during field visit in August 2009.

Scenes of Landsat ETM+ from period 1999 to 2003 were evaluated in previous work [2] for purpose of land cover mapping. Available scenes mainly for winter period were classified by MLC algorithm using the same set of training sets collected in overlapping area of two neighboring frames. The resulting classification images were stacked and the most frequent class in the stack was assigned to each pixel. Seven and twelve scenes were used for eastern and western frame respectively. It was found out that the wetlands cover 934.2 km^2 which is 7.2% of the total area of Nam Co basin.

2. METHODS

Since wetlands occupy characteristic position with respect to terrain, an area of potential wetlands can be delineated. This helps to avoid misinterpretation due to some terrain artifacts in the remote sensing data during the evaluation stage. A set of rules has been set up based on comparison of manually collected sample areas of wetlands and terrain derivatives. We examined statistics of sample data over following derivative of the SRTM DEM: terrain curvature, slope and the altitude itself. The utilization of more detailed GDEM had to be clearly ruled out due to the presence of many artifacts that become even amplified in the derived terrain-feature images. Ranges of typical values for the wetlands have been calculated for the derivatives based on mean values and standard deviations. Using these rules we extracted a binary layer that delimits areas favorable for presence of wetlands in terms of relief.

Changes of wetland area were studied using a time series of data provided by optical sensors that covers last 44 years. The oldest images from 1965 were acquired by Corona reconnaissance satellite. The rest of the time span is covered by Landsat data. There are plenty of cloud free Landsat scenes available for the region. Majority of them were acquired in dry period from October to April. Cloud free summer scenes with good contrast between wetlands and surrounding grasslands are rare. We used following datasets for analysis of changes of wetland area in Nam Co basin: Corona scene from 25/5/1965, TM scene from 14/9/1991, ETM+ scene from 13/6/2001 and 14/11/2004. In order to identify major processes that lead to extent changes and to assess the overall trend we selected an area in SE part of the basin with various wetland types. There are wetlands along the lake shore, along streams and on foothills of mountains. The surface of wetlands is often non-homogenous in terms of spectral response. This is truth also in case of wetlands in Nam co basin. The spectral differences inside larger wetland area reflect variations of vegetation cover, moisture content, presence of surface water and relief. These variations are difficult to account for in an automatic classification method. We delineated wetlands in the study area by combination of region growing algorithm and manual editing over suitable band combination. On the ETM+ scene from 4/11/2004 we took advantage of high contrast between snow covered grassland and snow free wetlands with high grass. Each resulting layer representing wetlands was checked against the mask of potential wetlands and the areas in topographically unfavorable settings were excluded.

We examined thermal properties of wetlands on thermal infrared bands from Landsat ETM+ for period between April 2000 to and June 2001. The data was calibrated to surface temperature applying the inverse of Planck function. The difference of temperature between wetlands and the surrounding grassland has been checked on a set of manually selected samples of these two surface types. The samples have been identified based field experience during a field visit in summer 2009. Samples for steeper wetlands on foothills and samples for flat wetlands were checked separately.

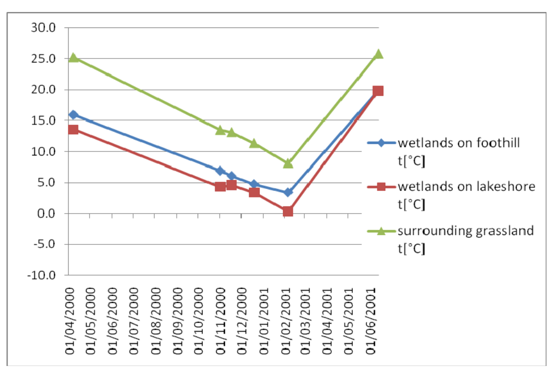


Figure 2. Surface temperatures of sample areas of wetlands and surrounded grasslands derived from thermal infrared band of Landsat ETM+.

In order to understand potential of thermal data to distinguish different features of internal structure of wetlands we examined thermal data over a period of several months. Our assumption is that even though the temperature patterns inside wetlands are variable between particular dates in long term they could represent stable functional features in the wetlands. We expect more stable behavior in case that the images are from the same season. Image of standard deviation of six thermal bands was calculated. The resulting pattern of standard deviation with respect to their position in terrain and drainage pattern was examined. Three bands from winter season 2000-1 were visualized in RGB synthesis (R: 5/2/2001, G: 17/11/2000, B: 1/11/2000) for an area in SW part of the basin. We compared the image with result of unsupervised classification of TerraSAR ScanSAR scene from 4/9/2009.

Potential of multi-frequency and multi-polarization SAR data for mapping of wetlands and their surface properties in Nam Co basin has been examined. We used TerraSAR-X single and dual polarization data in Strip mode, TerraSAR-X ScanSAR data and ALOS/PALSAR L-band quad polarization data. Two TerraSAR-X strip map scenes in dual polarization mode have been acquired simultaneously with field measurements of soil moisture and roughness in August 2009. The scenes have been de-speckled by multiple application of Lee filter. Orthorectification has been based on SRTM and GDEM without use of ground control. Accurate DGPS measurements and more detailed elevation model that would fit the high spatial resolution of the TerraSAR data were not available. We checked dependency of X-band signal of wetlands on rain induced humidity on two TerraSAR-X scenes in Image mode. The scenes were acquired in two consecutive days in August 2009. We examined scattering mechanism that take place on hummocky surface of wetlands on ALOS/PALSAR using Pauli decomposition image.

One TerraSAR scene from 4/9/2009 in ScanSAR mode was classified by unsupervised classification. The scene covers approximately half of the area of Nam Co basin. Three backscattering classes correspond to wetlands. Misclassifications in mountain areas due to influence of terrain shadows were eliminated utilizing the mask of potential wetlands (Fig. 5).

3. RESULTS

In order to improve mapping of wetlands a layer of potential wetlands with respect to terrain for Nam Co basin has been produced. Following rules resulted from statistical analysis of wetland samples: maximum altitude 5100m, maximum terrain curvature -10 (concave and flat areas) and maximum slope inclination 6.1 degrees. Maximum slope inclination 6.1 fits wetlands of the samples but it was changed to 8 degrees since a wetland that reaches this inclination has been found during the field visit. This map appeared to useful for delineation of wetlands since it prevents some misclassifications caused by terrain artifacts in the satellite data. It has been seen that the more detailed elevation model GDEM in its present version could not have been used since it contains too many errors caused by the production method.

Analysis of the time series of the optical images showed that some parts of wetlands close to lakeshore were flooded since 1965. The shift of the shoreline reached up to around 1.5 km in very flat parts (Fig. 3). The transgression led obviously also to change of moisture conditions of areas approached by the lakeshore. Lack of drainage led to development of new wetlands. The wetlands on foothills and the wetlands around streams stayed relatively stable. The wetland area growth and loss seems to be quite balanced. A subset of the studied area is shown on (Fig. 4). More extensive research has to be carried out for quantification of the trend.

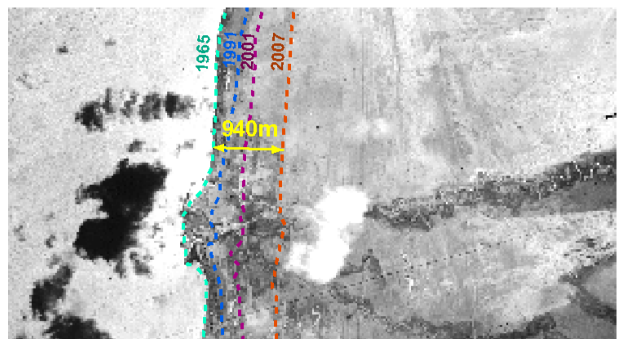
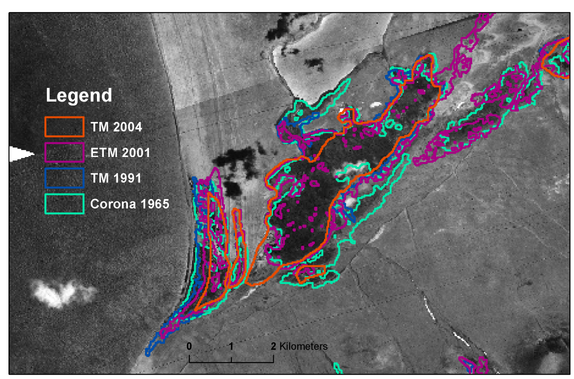


Figure 3. Transgression of the flat eastern shore of Nam Co between 1965 and 2007 that led to flooding of some wetlands.



Fiure 4. Changes of wetland area in SE part of Nam Co basin in years 1965 (Corona), 1991 (TM), 2001 (ETM +) and 2004 (TM). Flooded part during gradual transgression can be seen on the left margin.

Thermal infrared band of Landsat proved to be useful for

wetland detection. Wetlands in Nam Co basin have distinct signature in thermal bands of Landsat ETM+ (Fig. 2). High thermal inertia of humid soil causes lower temperature with respect to surrounding grasslands in time of Landsat overflight.
The mean difference of temperature with respect to surrounding grassland is 6.7 °C in case of wetlands on foothills and 8.5 °C in case of wetlands in flat areas. This difference (during Landsat overflight at around 10 a.m.) did not change considerably in the period from April 2000 to June 2001 (Fig. 2).

The RGB synthesis of selected Landsat ETM+ infrared thermal bands for winter season 2000-1 features fairly good discrimination of wetlands (dark orange patches) (Fig. 5.).

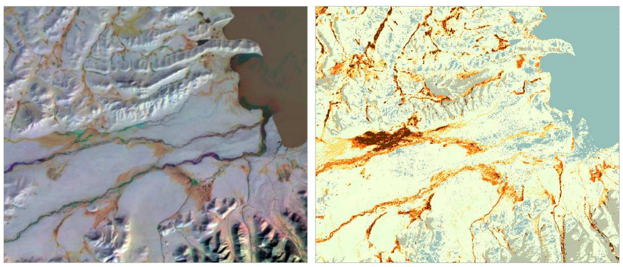


Figure 5. Comparison of RGB synthesis of Landsat ETM+ thermal bands for winter period 2000-1 and unsupervised classification of TerraSAR ScanSAR scene (4/9/2009). Wetlands in both images are in orange-brown tones.

TerraSAR scenes in dual polarization allowed us to distinguish major areas with different moisture regimes inside the wetlands (Fig. 6). Reaction of backscattering properties on moisture from previous precipitation is well visible in the image from 12/8/2009. Water logged parts of wetlands can be distinguished from dryer areas on high level of resolution. Dryer parts with less surface water are yellow, moist parts with surface water in blue and violet, surrounding grassland in green. Differences if backscattering mechanism due to changes of moisture between the two acquisitions can be seen clearly.

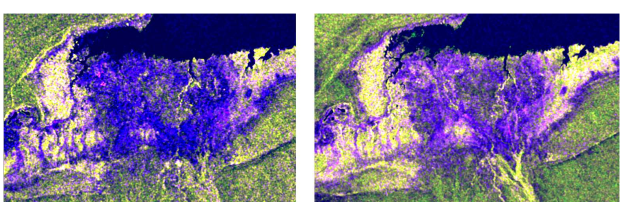


Figure 6. Subsets of two TerraSAR-X scenes in dual polarization (RGB synthesis: HH, VV, HH-VV) for wetland in a flat lake shore area from 12/8/2009 acquired in descending mode (left) and from 13/8/2009 in ascending mode (right).

Classes of wetlands in the classification of TerrSAR-X ScanSAR scene correspond well with wetlands in the RGB synthesis of thermal bands of ETM+. It shows good potential of both approaches.

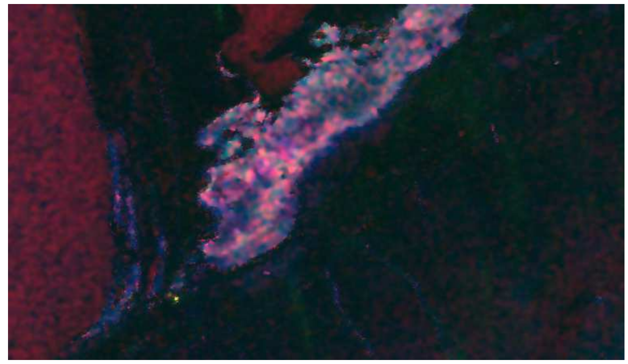


Figure 7. Pauli decomposition of ALOS/PALSAR full polarization scene (August 2006) features very good discrimination of wetlands (for comparison see Fig. 4)

The L-band data of ALOS/PALSAR have very good potential for delineation of wetlands. Wetlands have very distinct signature in terms of backscatter intensity as well as backscattering mechanisms in comparison to grassland. This is illustrated by a subset of Pauli decomposition image (Fig. 7.). The signal is driven by surface roughness caused by hummocky structure and by soil moisture.

4. CONCLUSIONS

Obtained results suggest that a combination of remote sensing data from multiple sensors enables mapping of wetlands on Tibetan Plateau. This approach allows mapping of internal structure of wetlands related to drainage patterns and different moisture regimes. Presence of surface water and humidity can be detected by proposed techniques. Relationship between surface properties of wetlands and underlying permafrost layer has to be better understood by further research.

5. ACKNOWLEDGMENTS

This research work has been supported by DFG priority program 1372 Tibetan Plateau: Formation - Climate - Ecosystems (TiP). The PALSAR data have been obtained through the cooperation between the Institute of Tibetan Plateau Research, CAS and JAXA (JAXA/METI for PALSAR) in JAXA's ALOS RA.

6. REFERENCES

1. Kang, S., Han, W., Zhou, S. & Huang, Z. (2006): Introduction to the Nam Co Monitoring and Research Station for Multisphere Interaction, Annual Report of Nam Co Monitoring and

Research Station for Multisphere Interaction, Chinese Academy of Science, Volume 1.

2. Kropáček, J., Hochschild, V. (2009). Parametrization of integrated hydrological model of Nam Co lake catchment on Tibetan Plateau using synergy of SAR and optical data, IEEE Geoscience and Remote Sensing Symposium, Cape Town, South Africa, 2009.

3. Rebelo, L. (2009). Characterisation of inland wetlands in Africa, K&C Report – Phase 1, Online: http://www.eorc.jaxa.jp/ALOS/en/kyoto/phase_1/KC-Phase1-report_Rebelo.pdf, accessed 13.Nov. 2009.

4. Shengbo, C. (2004). Permafrost classification on the Tibet Plateau based on surface emissivity retrieval from Terra-MODIS data. IEEE Geoscience and Remote Sensing Symposium, 2004. Vol. 4, 2699–2702.

5. Tian, K., Liu, J., Kang, S., Campbell, I., Zhang, F., Zhang, Q. & Lu, W. (2009). Hydrothermal pattern of frozen soil in Nam Co lake basin, the Tibetan Plateau. *Environmental Geology.* **57**(8): 1775.

6. Warner, T. & Chen, X. (2001). Normalization of Landsat thermal imagery for the effects of solar heating and topography, *International Journal of Remote Sensing.* 22, 773-788.

7. Zhen, L, Huadong, G. (2000). Permafrost mapping in the Tibet plateau using polarimetric SAR. IEEE Geoscience and Remote Sensing Symposium. 5, 2024– 2026.